

# **CLARREO IR Spectral Radiances: Achieving 0.1 K 3-sigma (IR measurement science is ready for a Mission)**

Hank Revercomb

**University of Wisconsin-Madison,  
Space Science and Engineering Center**

**CLARREO SDT Meeting  
University of Wisconsin-Madison  
12-14 October 2011**



# IR Accuracy Requirements

**Radiance Accuracy:** **<0.1 K 2-sigma brightness T for combined measurement and sampling uncertainty** for annual averages of 15° zones (each <0.1 K 3-sigma) to approach goal of resolving a climate change signal in the decadal time frame

**On-orbit Verification and Test:** **Provide an On-orbit Absolute Radiance/Brightness Temperature Standard with an accuracy of <0.1 K 3-sigma** to provide SI traceability of on-orbit measurements



# Topics: IR Measurement Science

- **Background on IR Accuracy: Calibration and Validation of current sounders supports 0.1 K 3-sigma being achievable for CLARREO**
- **NASA Instrument Incubator Program (IIP) achievements demonstrate On-orbit Verification and Test System**

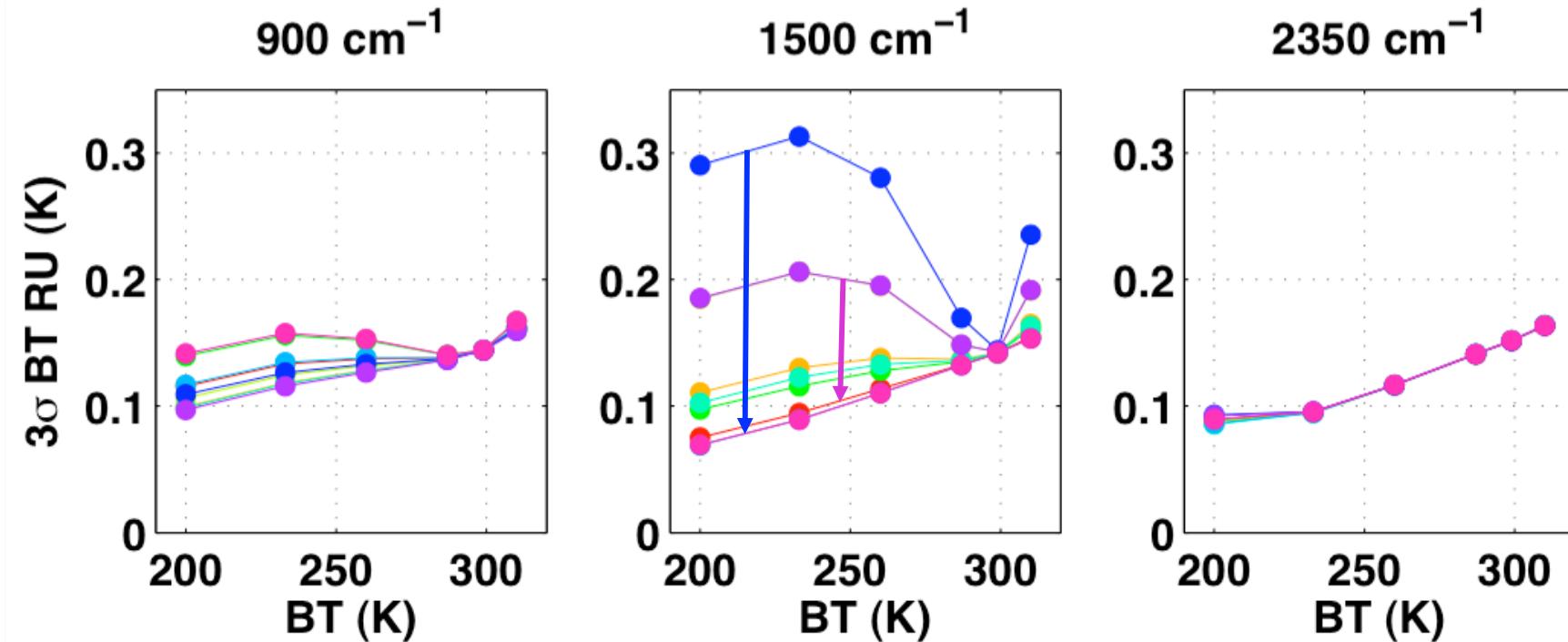
# Current System Capabilities

- **New High Resolution IR Sounders:** AIRS, IASI, CrIS...
  - Tremendous advance in information content & accuracy
  - Huge advance for climate process studies, offering
    - High vertical resolution T and WV profiling
    - Trace gas distributions
    - Cloud and surface properties
  - Provide a solid foundation for CLARREO IR feasibility
  - But, not optimized for unequivocal decadal trending
    - Biased diurnal sampling
    - Inconsistent and incomplete spectral coverage among platforms
    - Accuracy can be improved (by factor of 4-5)
    - SI traceability post-launch limited to aircraft inter-comparisons  
(sounder-to-sounder comparisons useful, but do not have direct, timely connections to International Standards)



## CrlS FM1 In-flight Radiometric Uncertainty: versus scene temperature for all FOVs for ~mid-band spectral channels

Generally < 0.2 K 3-sigma for all scene temperatures

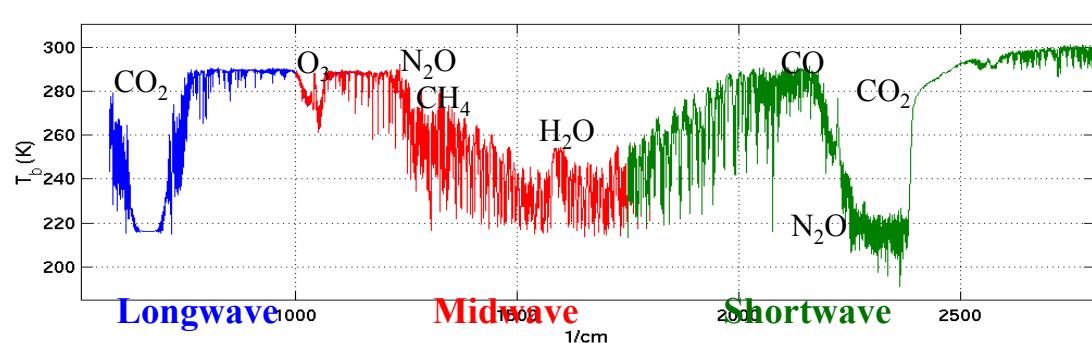


Non-linearity causing prominent FOV dependence (color coded)  
will be reduced significantly by in-flight FOV inter-comparisons

Tobin, D., J. Taylor, L. Borg, H. Revercomb, 2010: Expected On-orbit Radiometric Performance of the CrlS and comparisons with IASI and AIRS. CALCON Technical Conference, 23-26 August, Utah State University, Logan, UT.

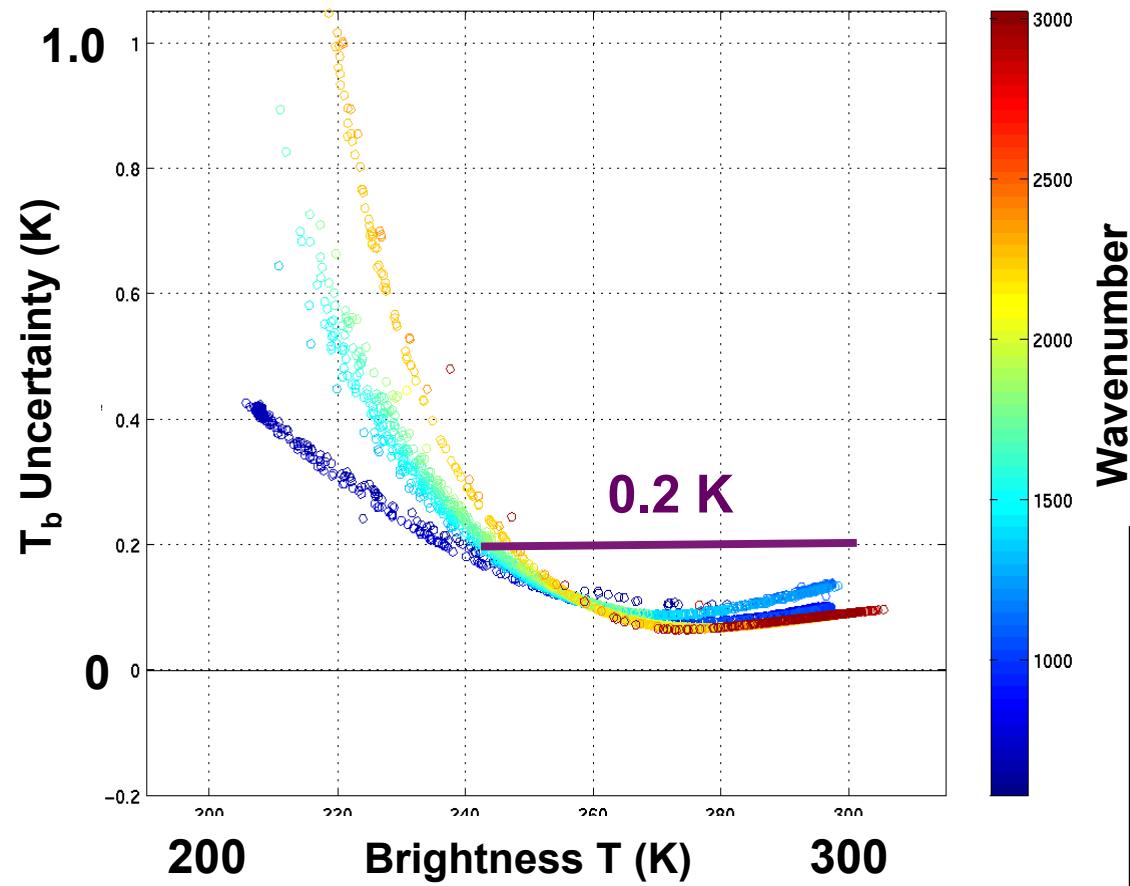
# UW Scanning HIS

Provides Sounder Inflight Validation



# S-HIS Absolute Radiometric Uncertainty for typical Earth scene spectrum

\*\*Formal 3-sigma absolute uncertainties, similar to that  
detailed for AERI in Best et al. CALCON 2003

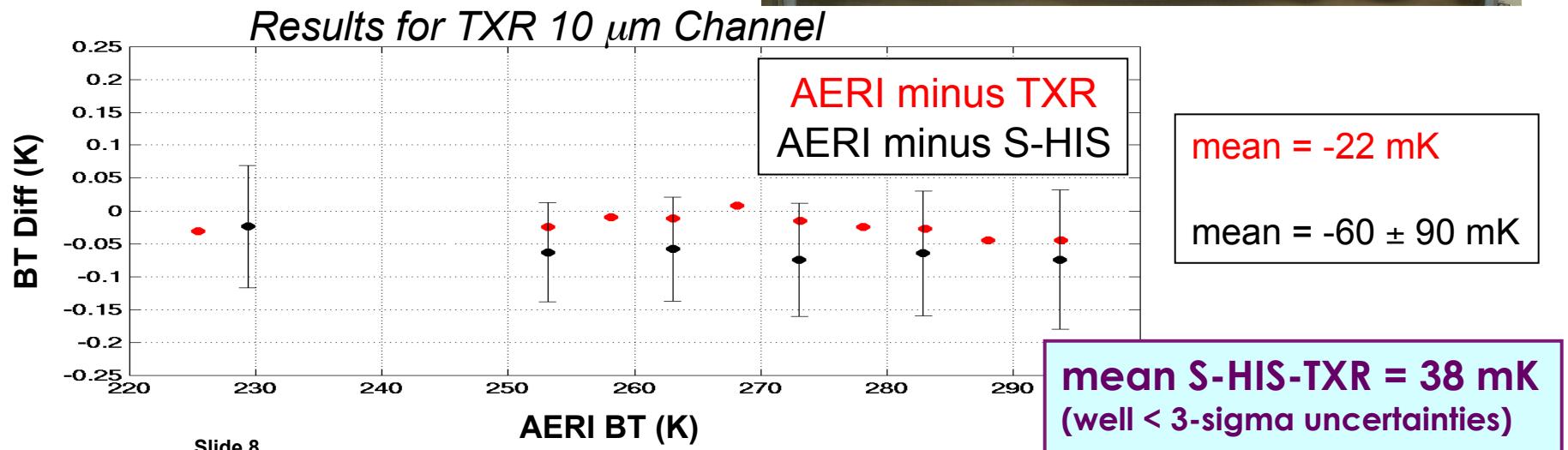
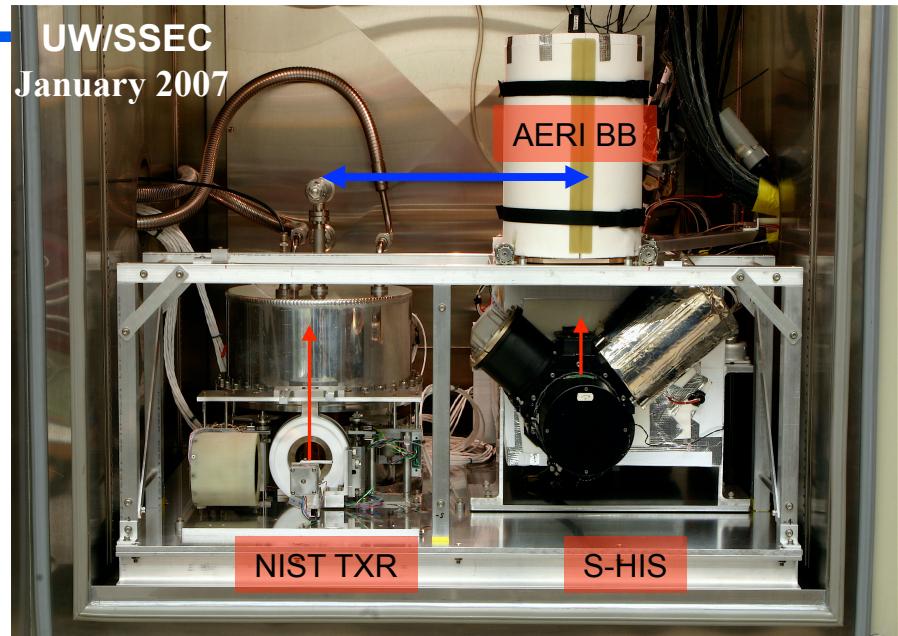


$T_{ABB} = 260 \text{ K}$   
 $T_{HBB} = 310 \text{ K}$   
 $\sigma T_{BB} = 0.10 \text{ K}$   
 $\sigma \varepsilon_{BB} = 0.0010$   
 $\sigma T_{refl} = 5 \text{ K}$   
10% nonlinearity

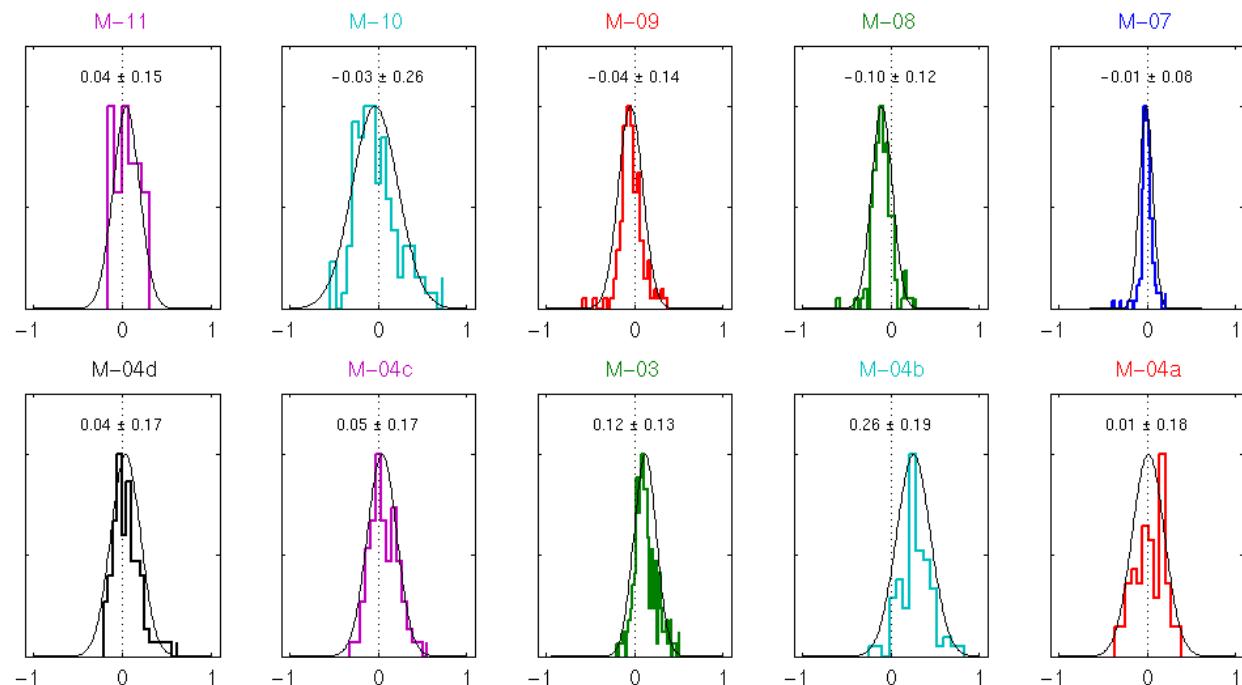
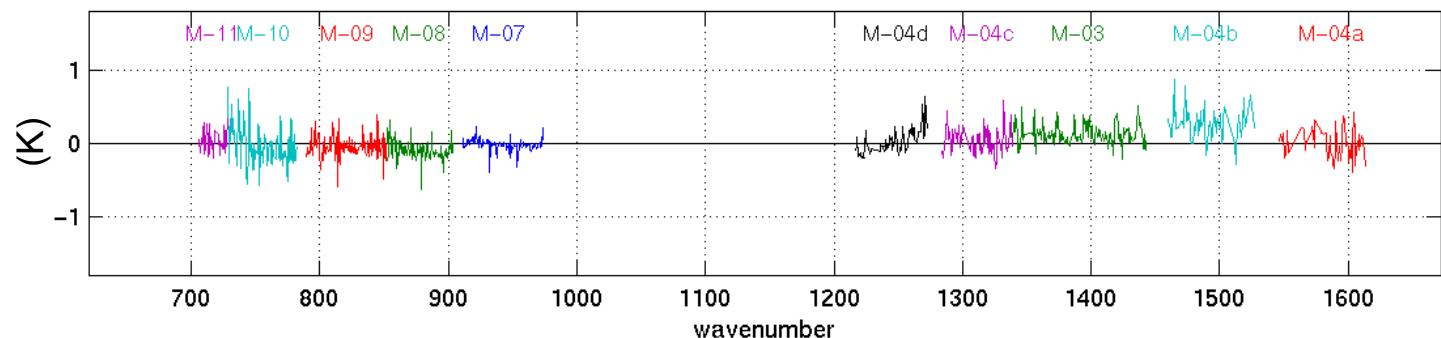


# UW S-HIS & AERI Blackbody Absolute Accuracy: The NIST Connection for SI Traceability

End-to-end S-HIS radiance evaluations conducted under S-HIS flight-like conditions with NIST transfer sensor (TXR) such that S-HIS satellite validation & AERI observations are traceable to the NIST radiance scale



# Example S-HIS Validation of AIRS



21 November 2002

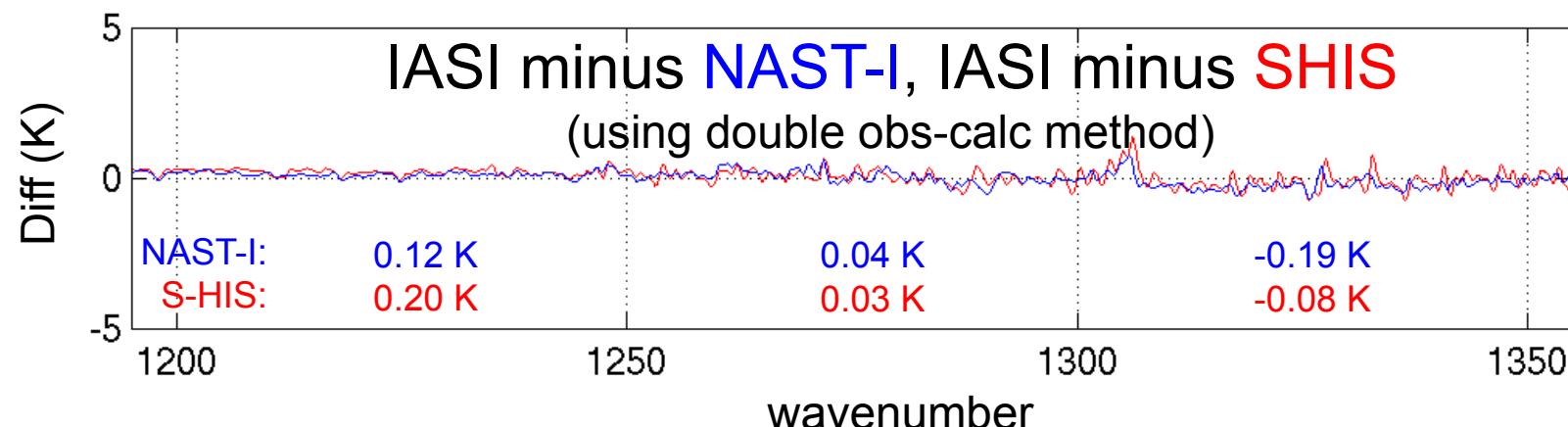
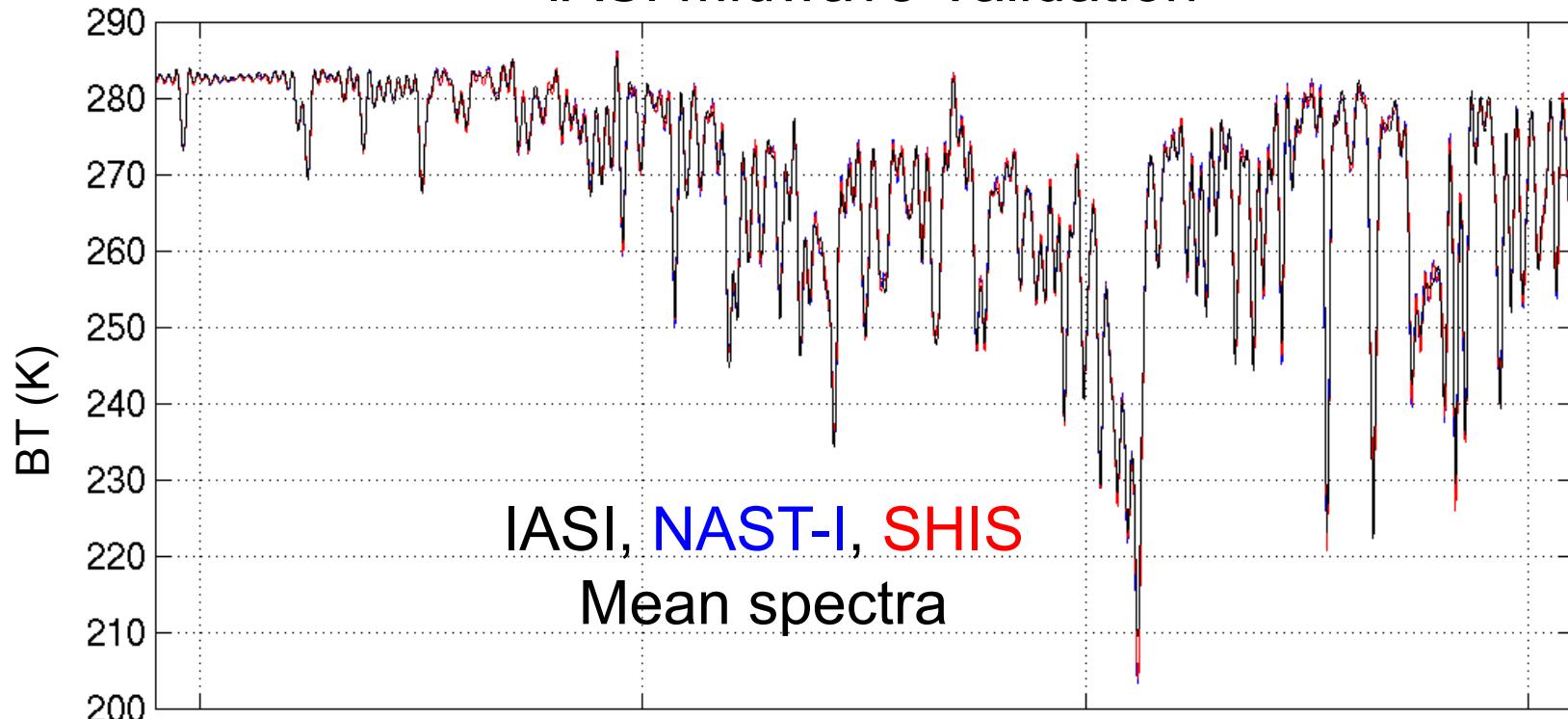


Tobin, D.C., et al., 2006: *J. Geophys. Res.*, 111, doi:10.1029/2005JD006094.

Slide 9

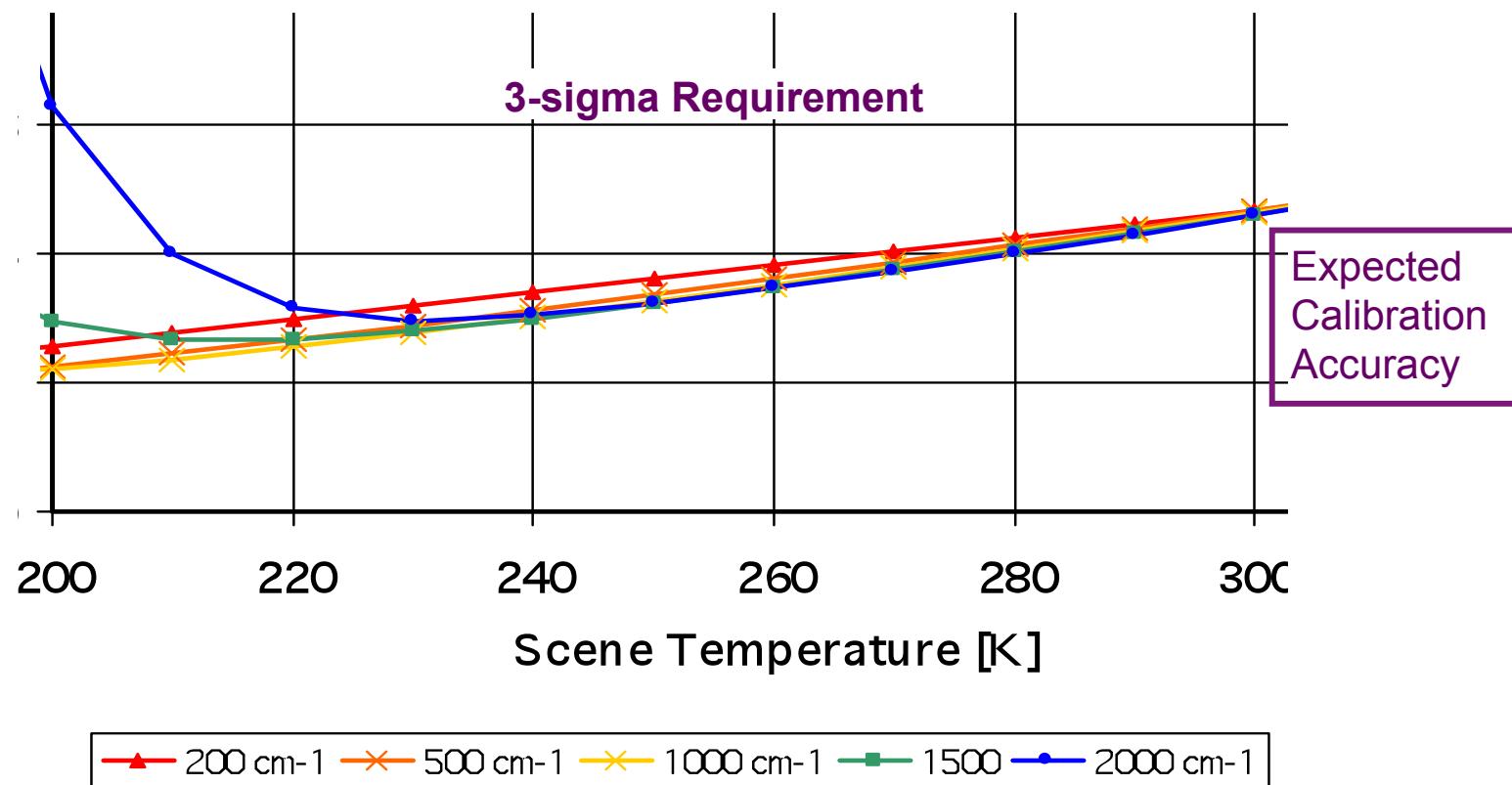


## IASI Midwave Validation



# IR Measurement Accuracy

< 0.1 K 3-sigma brightness T accuracy is achievable  
by applying proven techniques with simplified instrument design  
(nadir only, high S/N not needed, can avoid polarization errors & minimize non-linearity)



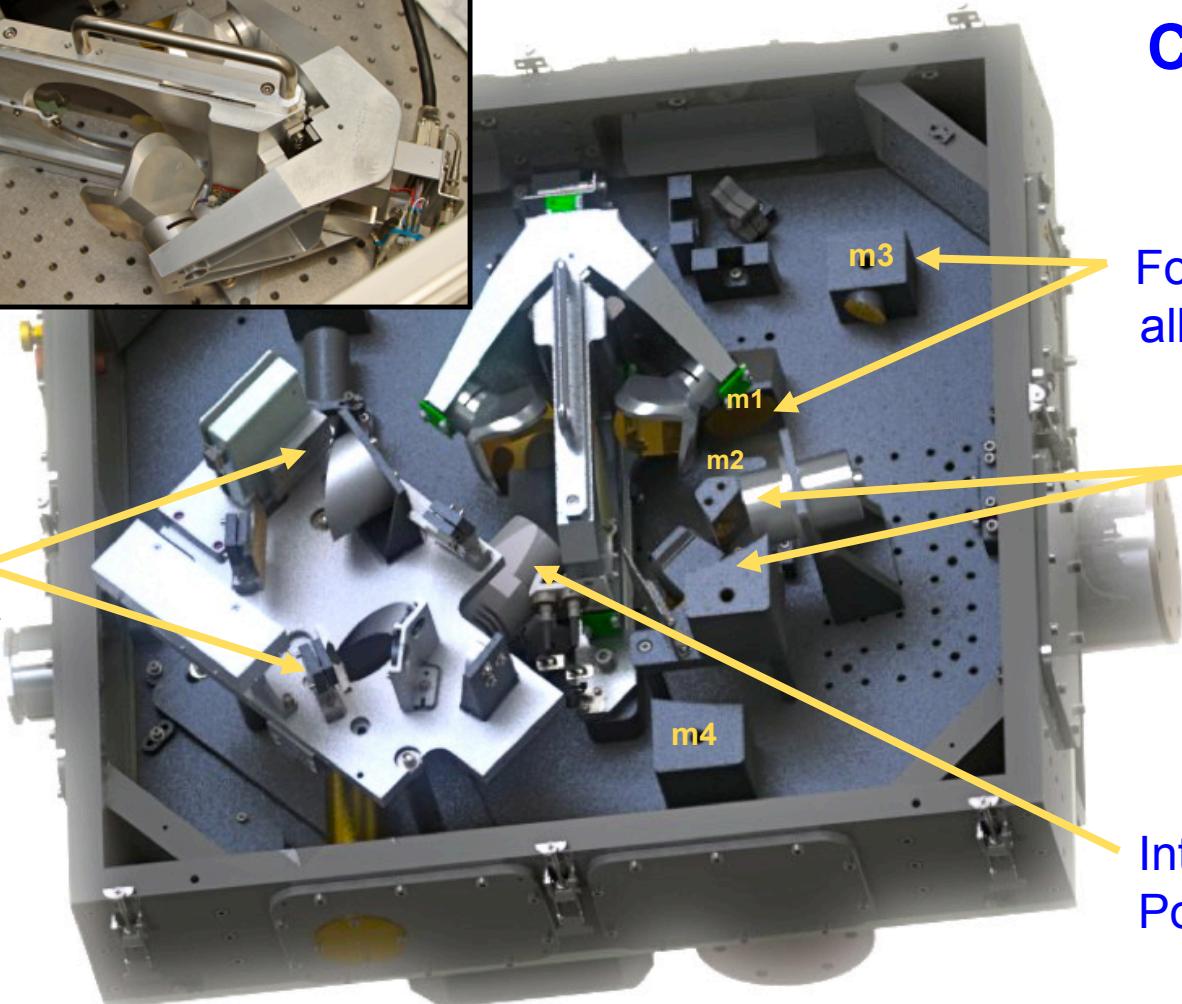
# Topics: IR Measurement Science

- **Background on IR Accuracy: Calibration and Validation of current sounders supports 0.1 K 3-sigma being achievable for CLARREO**
- **NASA Instrument Incubator Program (IIP) achievements demonstrate On-orbit Verification and Test System**

# Flight-like Breadboard Configuration

ABB  
Interfero-  
meter  
(corner cube,  
wishbone,  
CsI beam-  
splitter)

Pyroelectric  
Far IR Detector  
& all reflective  
Aft Optics



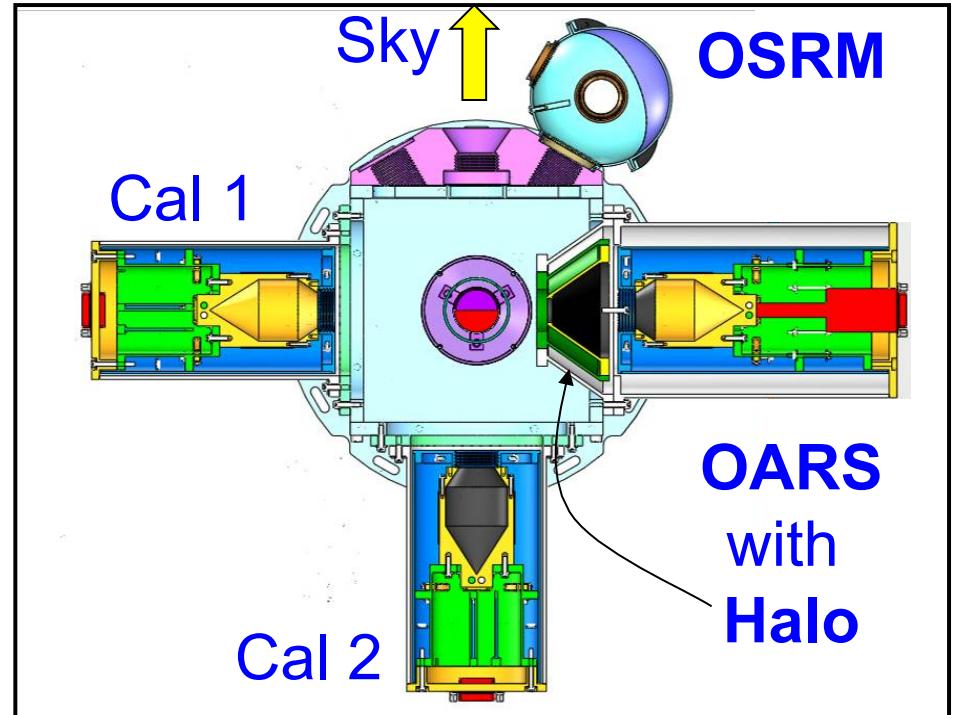
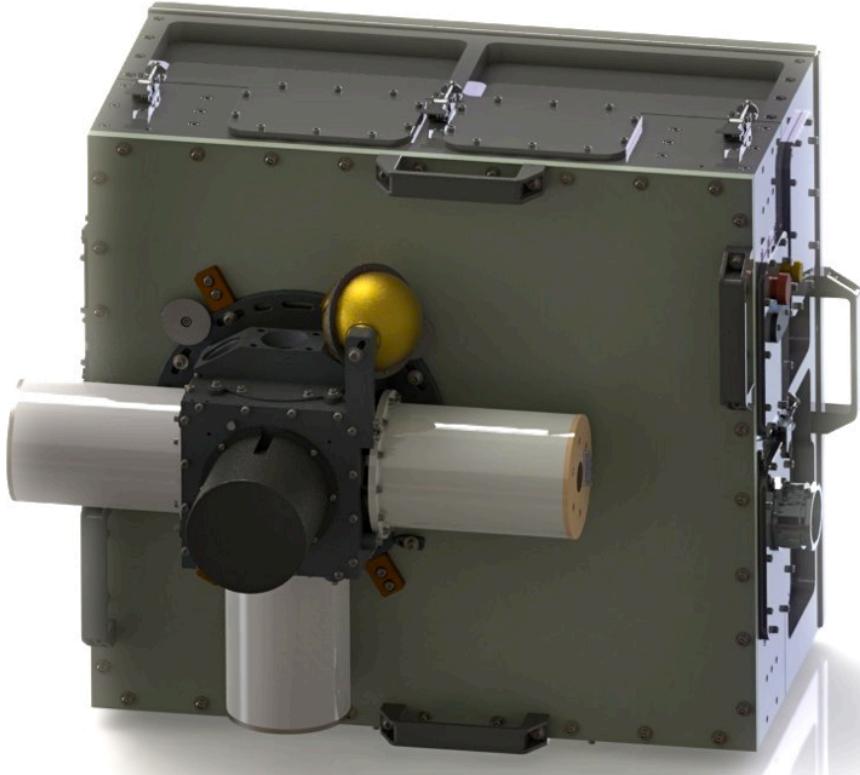
Calibrated  
FTS

Fore Optics-  
all reflective

Cryogenic  
Detector/  
Dewar &  
Aft Optics

Internal Input  
Port 2 Source

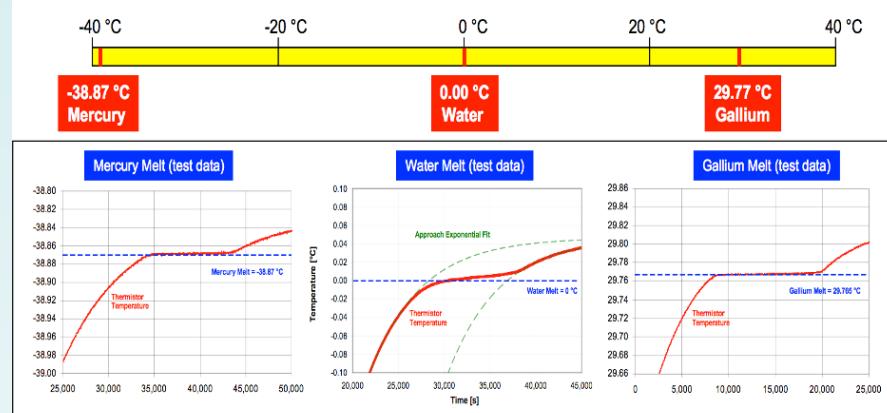
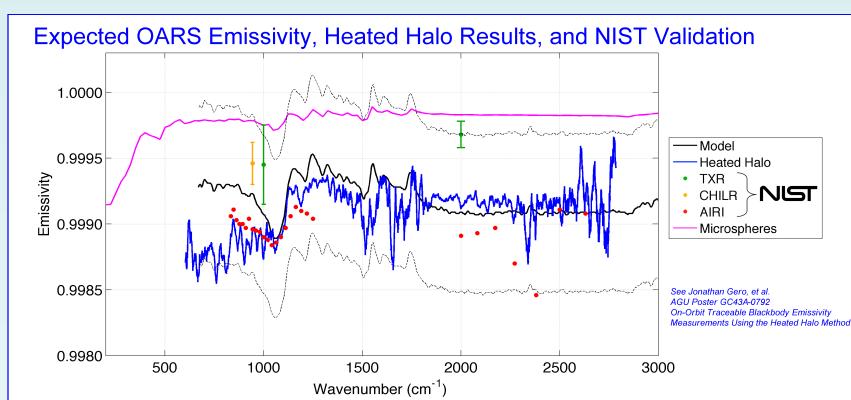
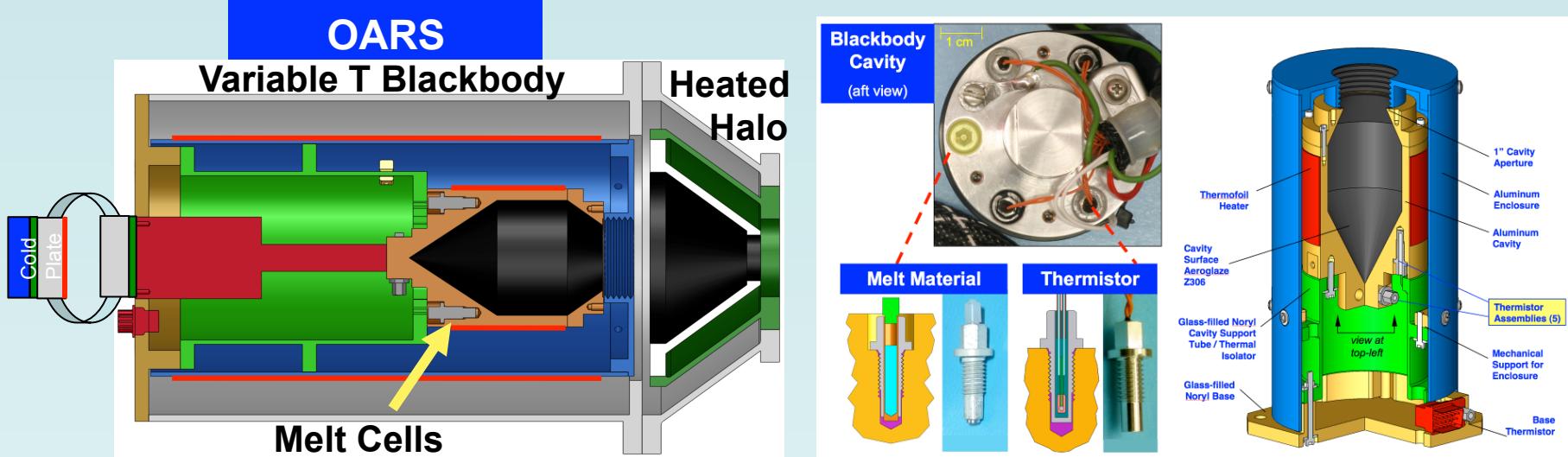
# On-Orbit Verification & Test System



- 3 cm aperture Sources
- 45° Gold Scene Select Mirror
- 2 Blackbodies for Calibration

**OARS:** On-orbit Absolute Radiance Standard  
**OSRM:** On-orbit Spectral Response Module (QCL source)

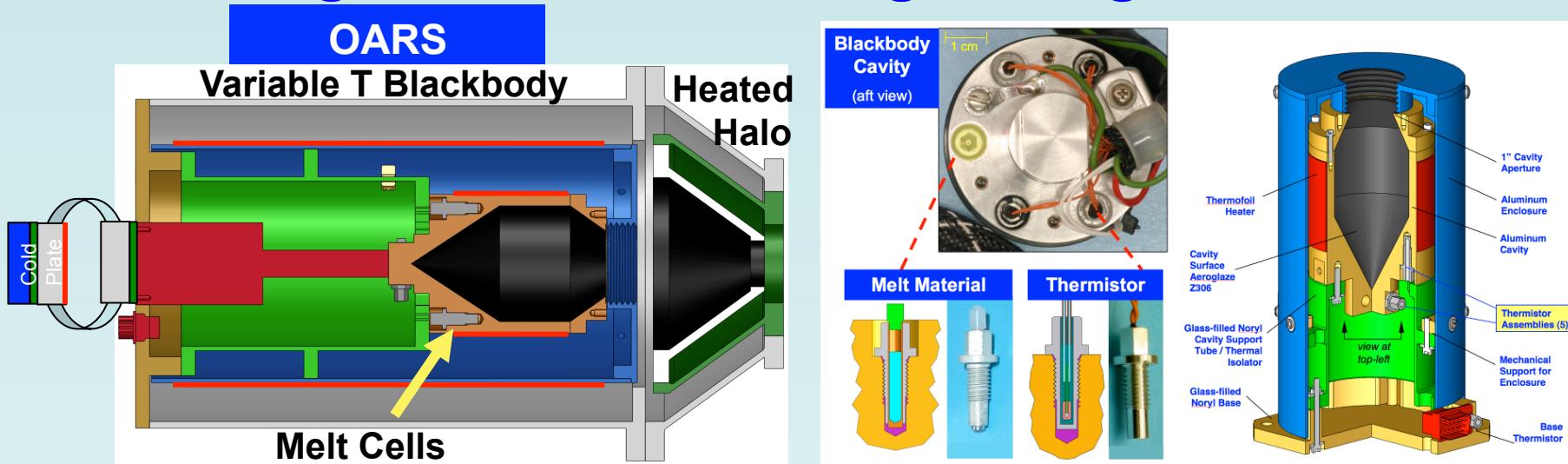
# On-Orbit Absolute Radiance Standard allowing calibration testing throughout mission



High Emissivity, Measured On-orbit  
with halo and QCL source

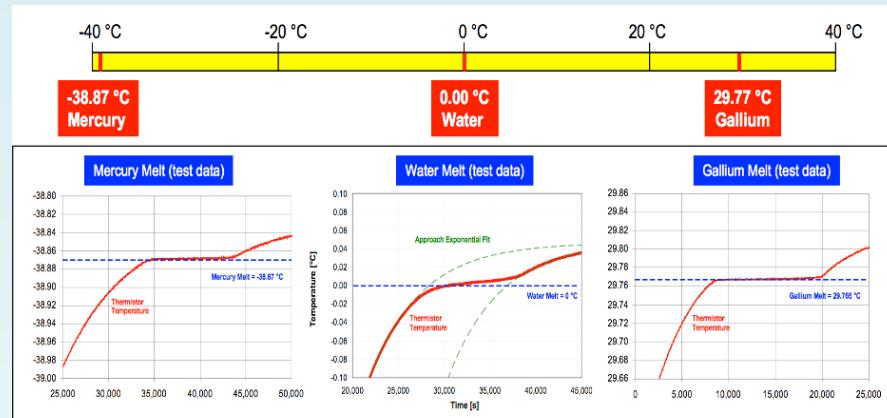
Absolute Temperature Calibration  
Using Multiple Phase Change Materials

# On-Orbit Absolute Radiance Standard allowing calibration testing throughout mission



Best, F.A., D.P. Adler, S.D.  
Ellington, et al., 2008: *Proc. SPIE*, 7081, 70810O.

Best, F.A., D.P. Adler, C.  
Pettersson, H.E. Revercomb,  
J.H. Perepezko, 2010:  
*Proc. SPIE*, 7857, 78570J: doi:  
10.1117/12.869564.

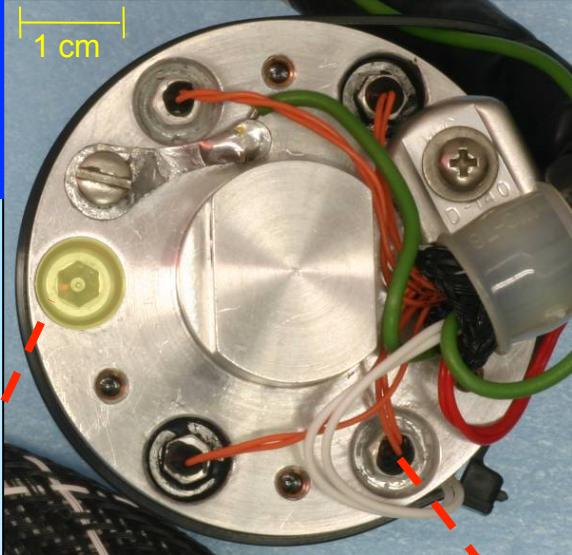


Absolute Temperature Calibration  
Using Multiple Phase Change Materials

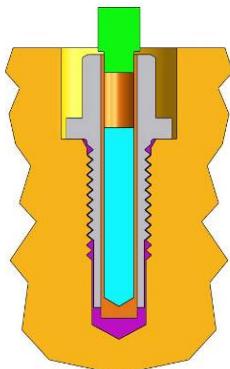
# SSEC GIFTs-type Cavity

(configured for melt signature tests)

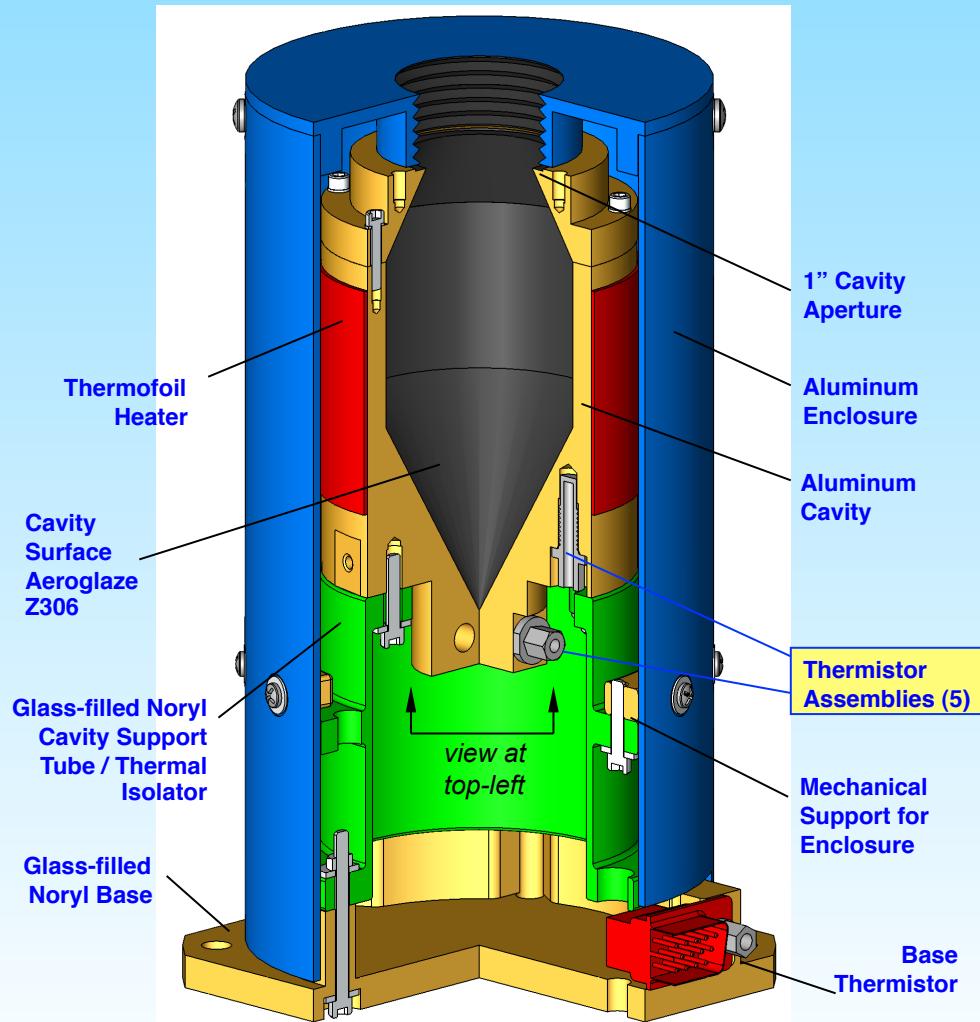
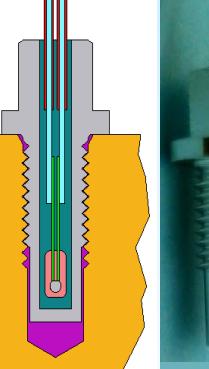
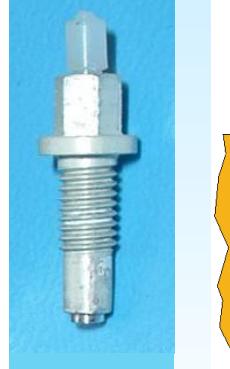
**Blackbody  
Cavity**  
(aft view)



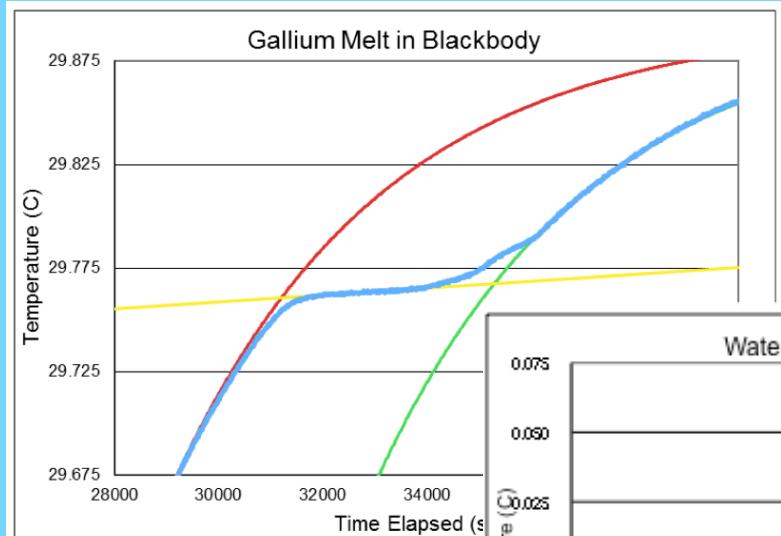
**Melt Material**



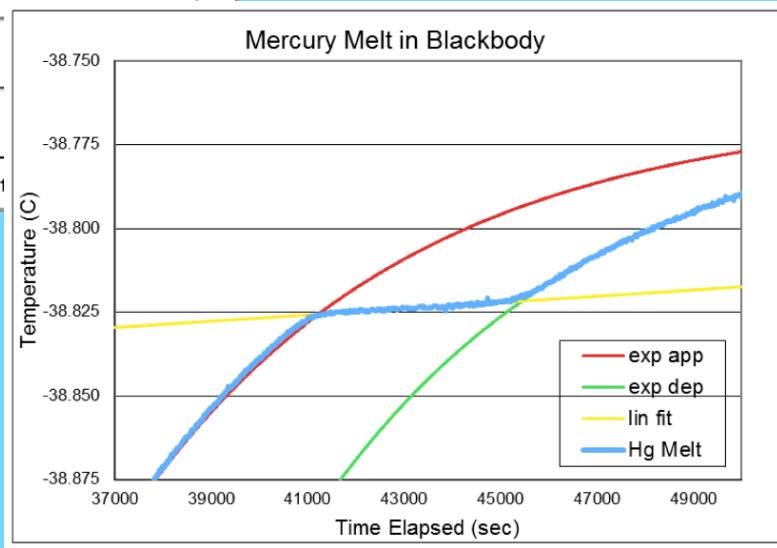
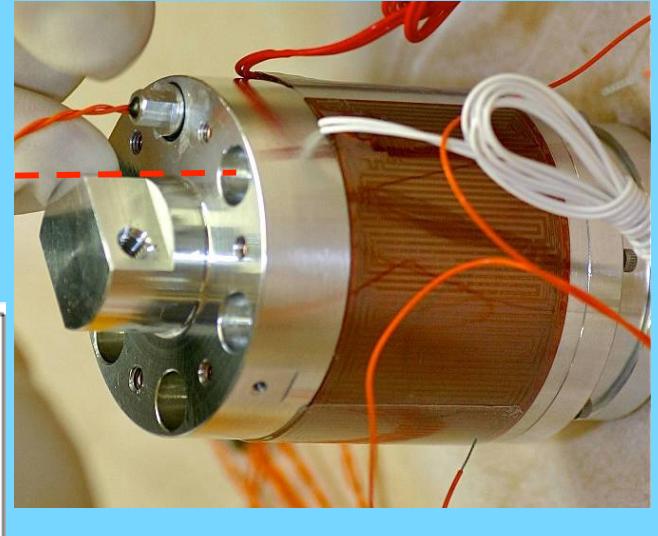
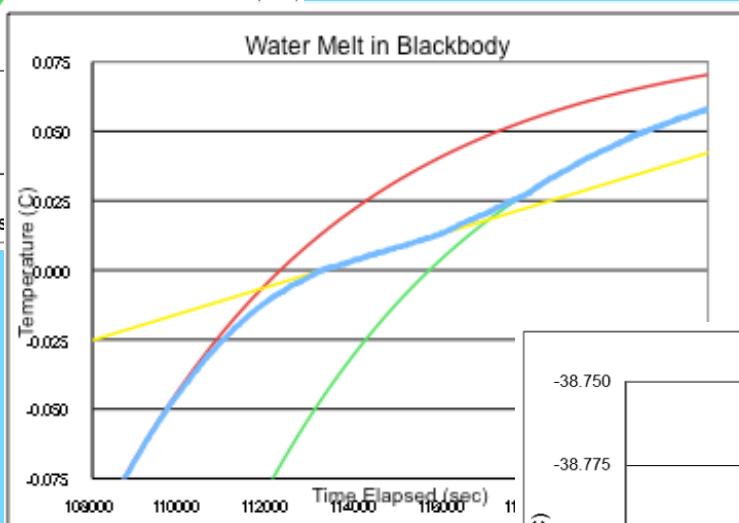
**Thermistor**



# Signatures in Blackbody demonstrate better than $\pm 5\text{mK}$ accuracy

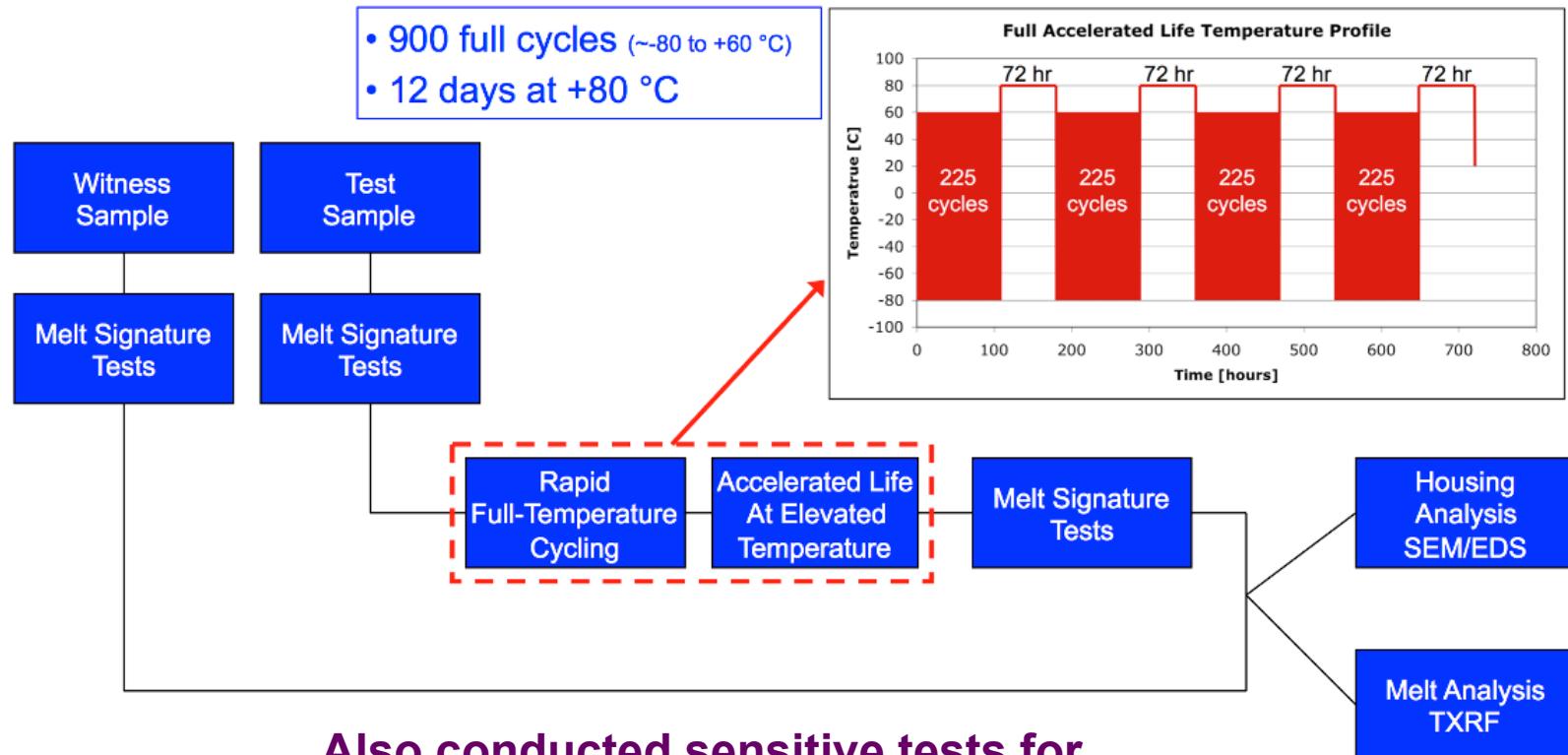


Water Melt in Blackbody



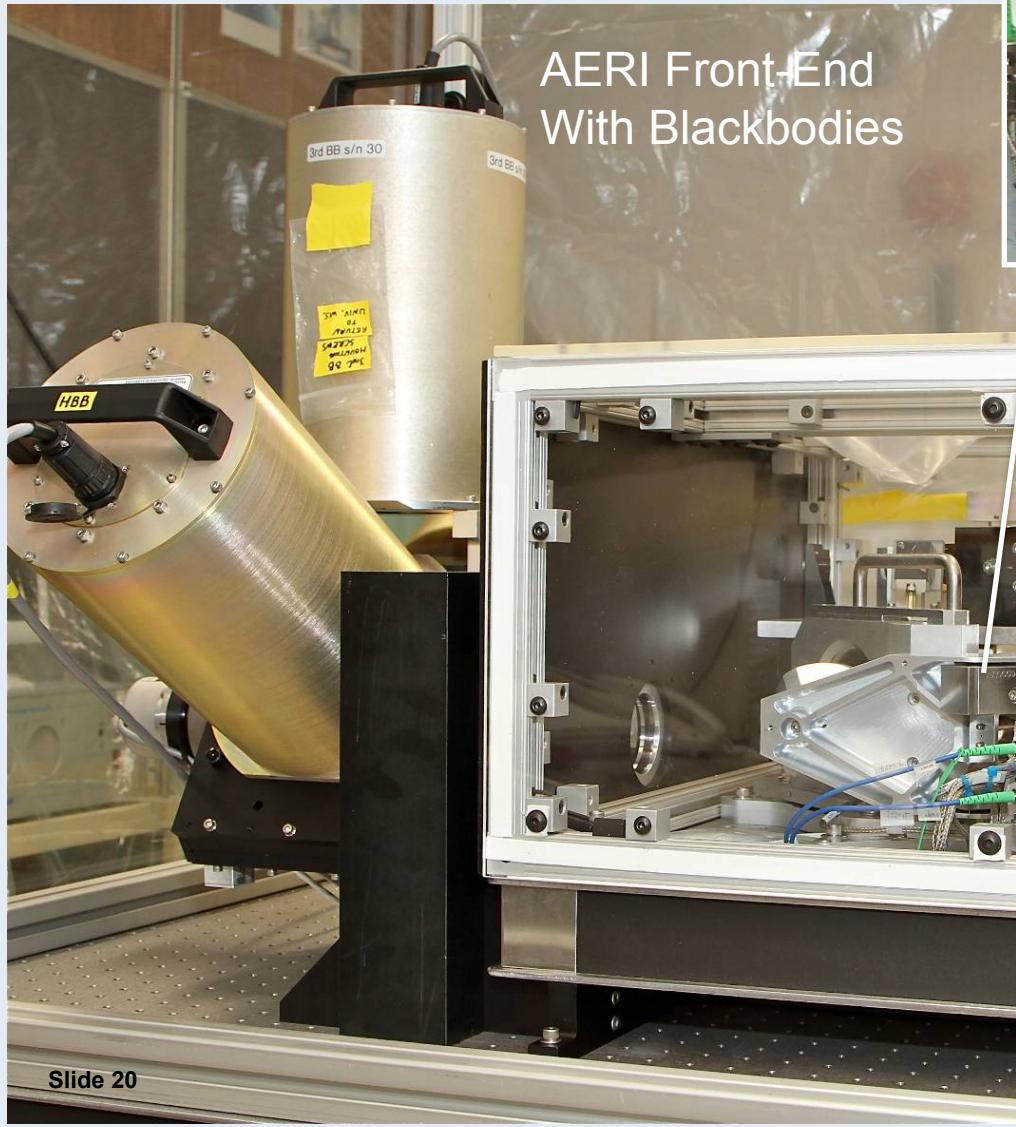
Miniature Phase Change Cells Integrated Into Blackbody and Signatures Obtained

# Accelerated Life Test: Ga, H<sub>2</sub>O, and Hg Packaged in Welded Housings

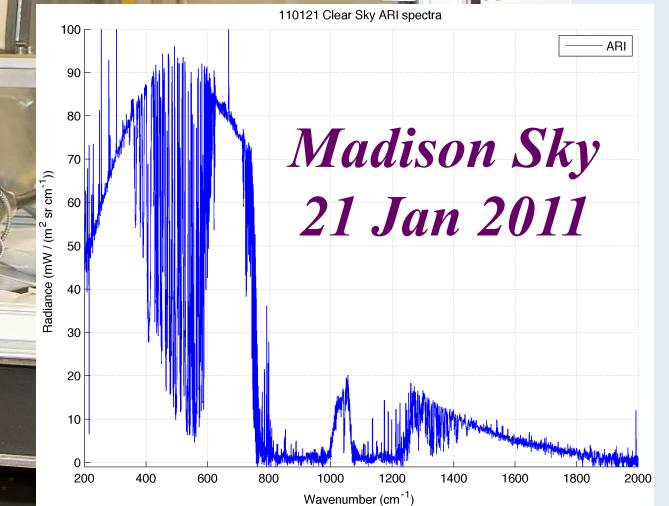


Also conducted sensitive tests for mechanical integrity, liquid metal embrittlement & dissolution

# UW Breadboard ARI-1 Results Summary



AERI Front-End  
With Blackbodies



*Madison Sky  
21 Jan 2011*

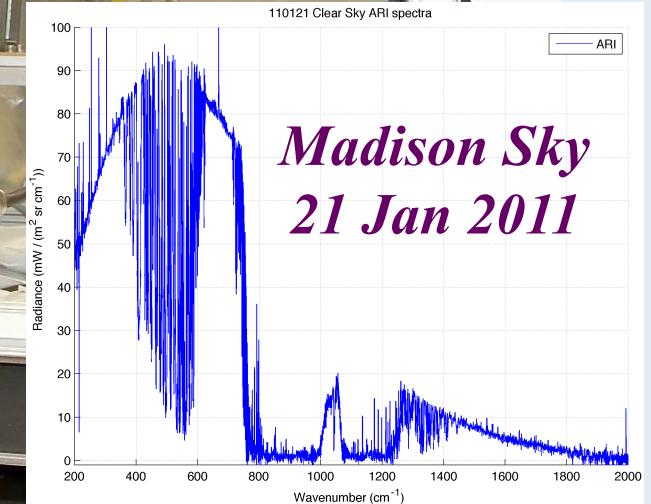
# UW Breadboard ARI-1 Results Summary



AERI Front-End  
With Blackbodies

## New Test Results

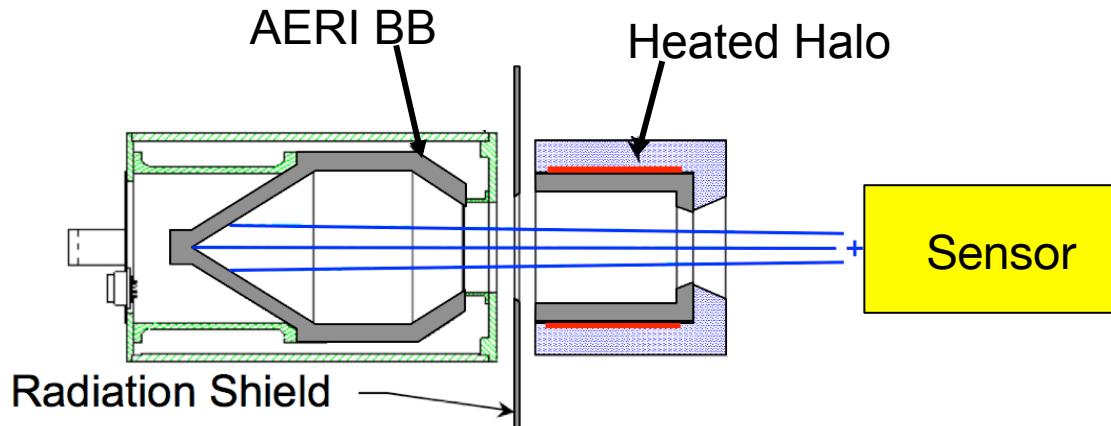
1. Longwave Emissivity Measurement
2. Pyroelectric Linearity
3. Ice Body Calibration



*Madison Sky  
21 Jan 2011*



# Heated Halo Concept for $\epsilon$ measurement

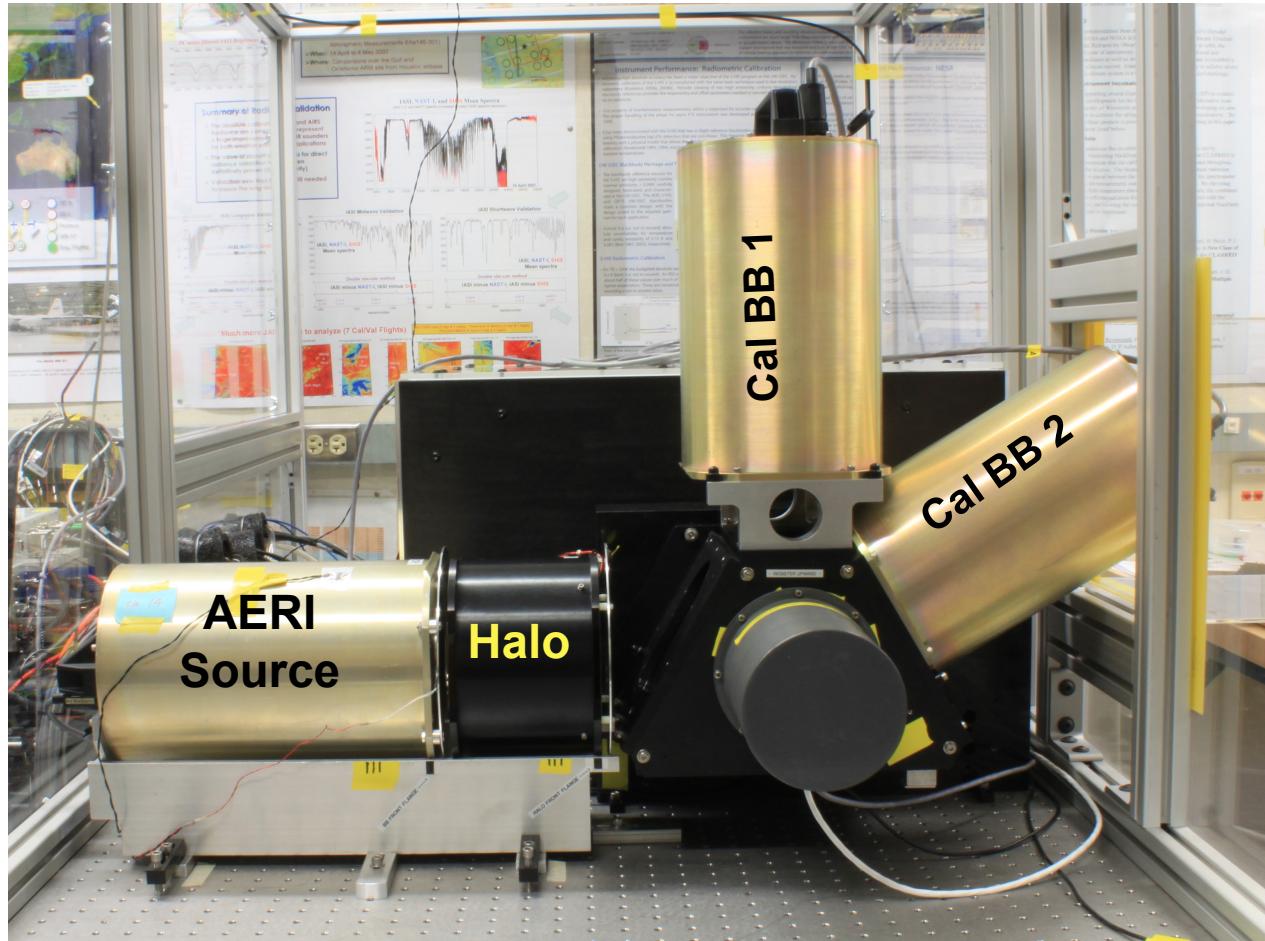


$$R_{\text{obs}} = \underbrace{\varepsilon \bullet B(T_{\text{bb}})}_{\text{Direct radiance from BB}} + \underbrace{(1 - \varepsilon) \bullet [F \bullet B(T_{\text{halo}}) + (1 - F) \bullet B(T_{\text{room}})]}_{\text{Background radiance reflected: } R_{\text{bg}}}$$

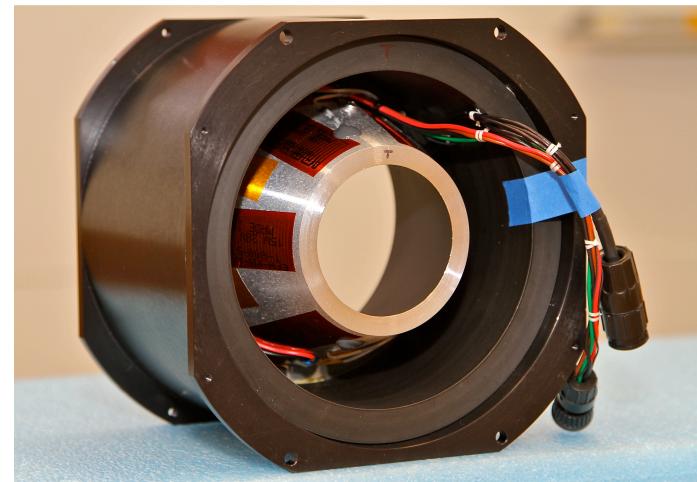
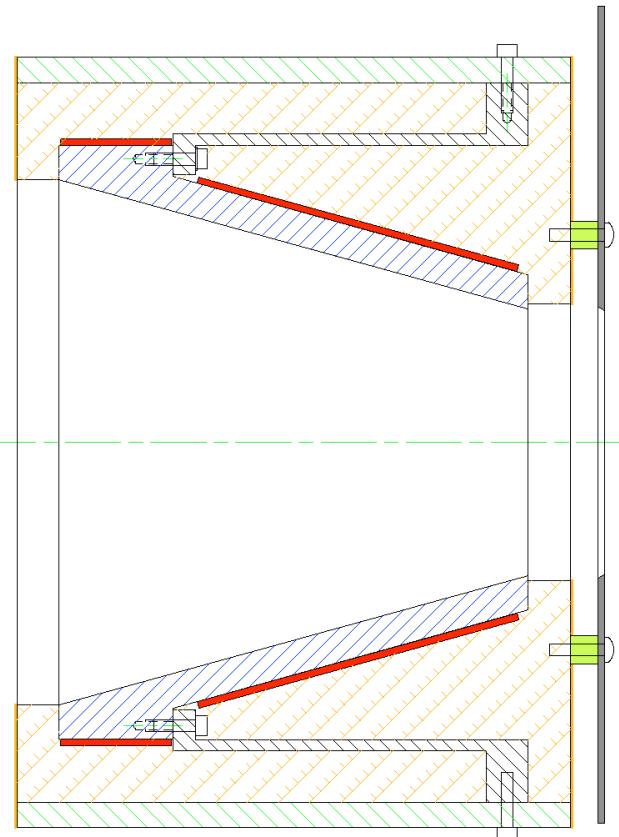
*Measured  
Reflectivity/  
Emissivity*

$$\langle 1 - \varepsilon(t) \rangle_t = \left\langle \frac{R_{\text{obs}}(t) - B[T_{\text{bb}}(t)]}{R_{\text{bg}}(t) - B[T_{\text{bb}}(t)]} \right\rangle_t$$

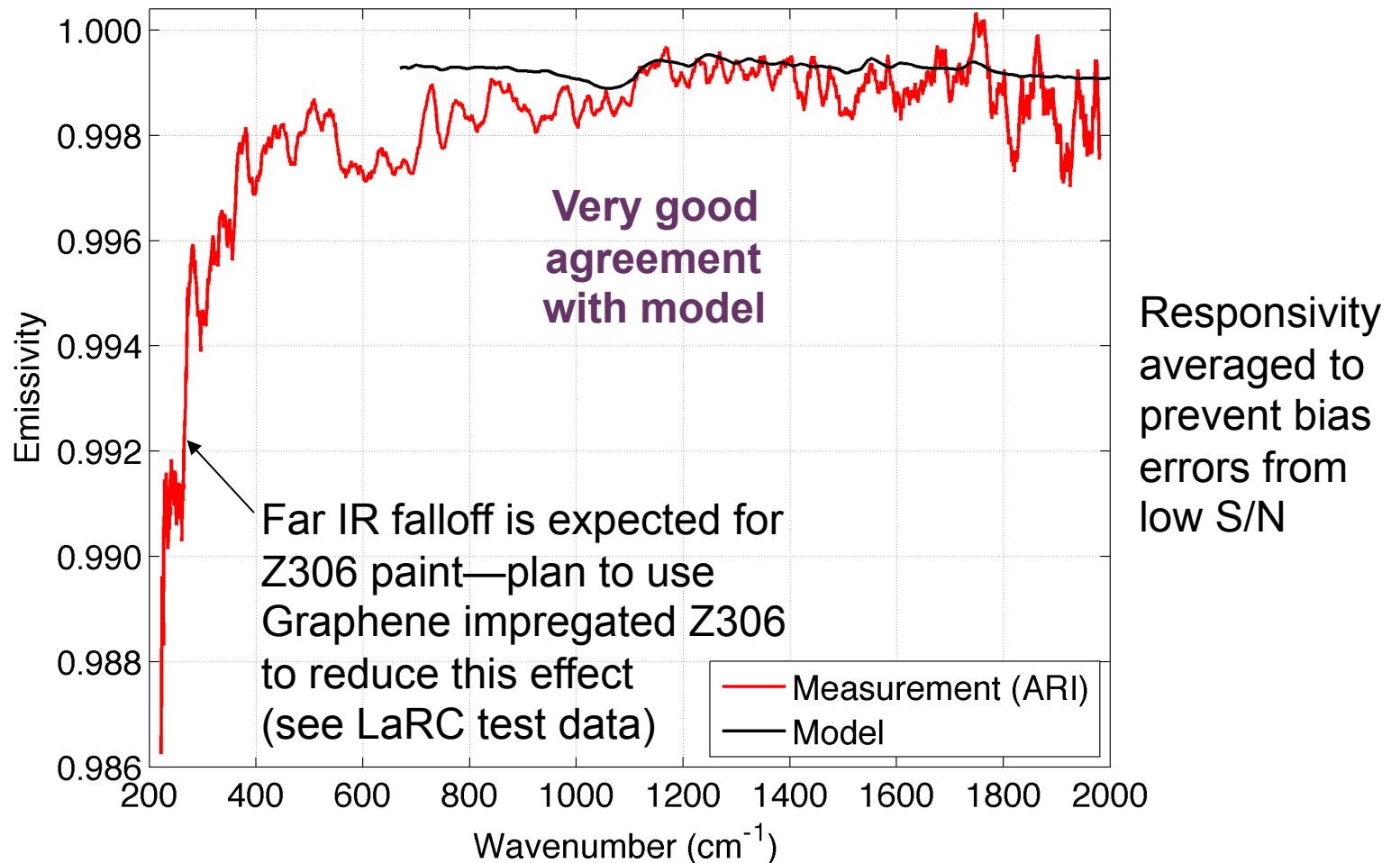
# Heated Halo Test Configuration



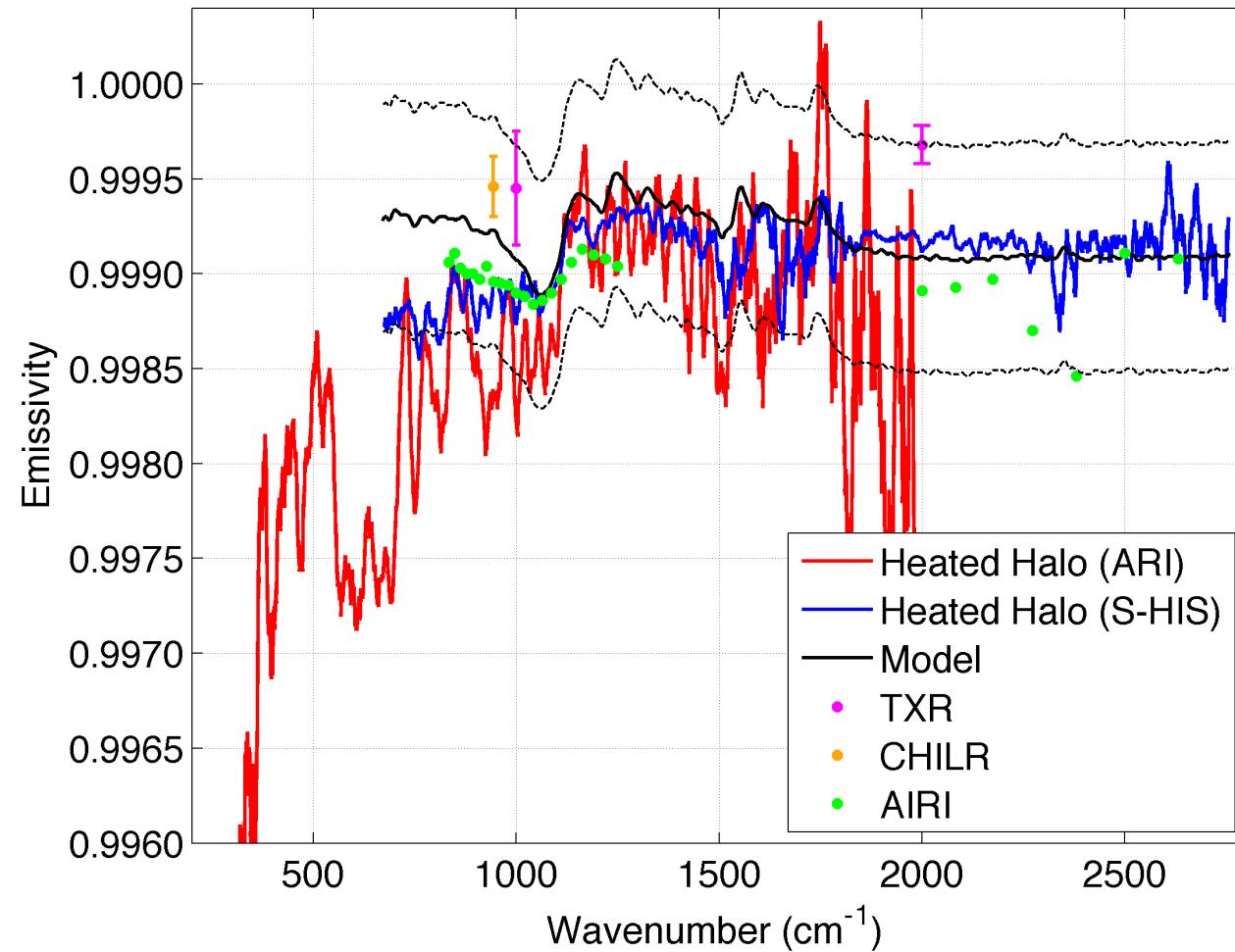
# Heated Halo Details (Generation 2)



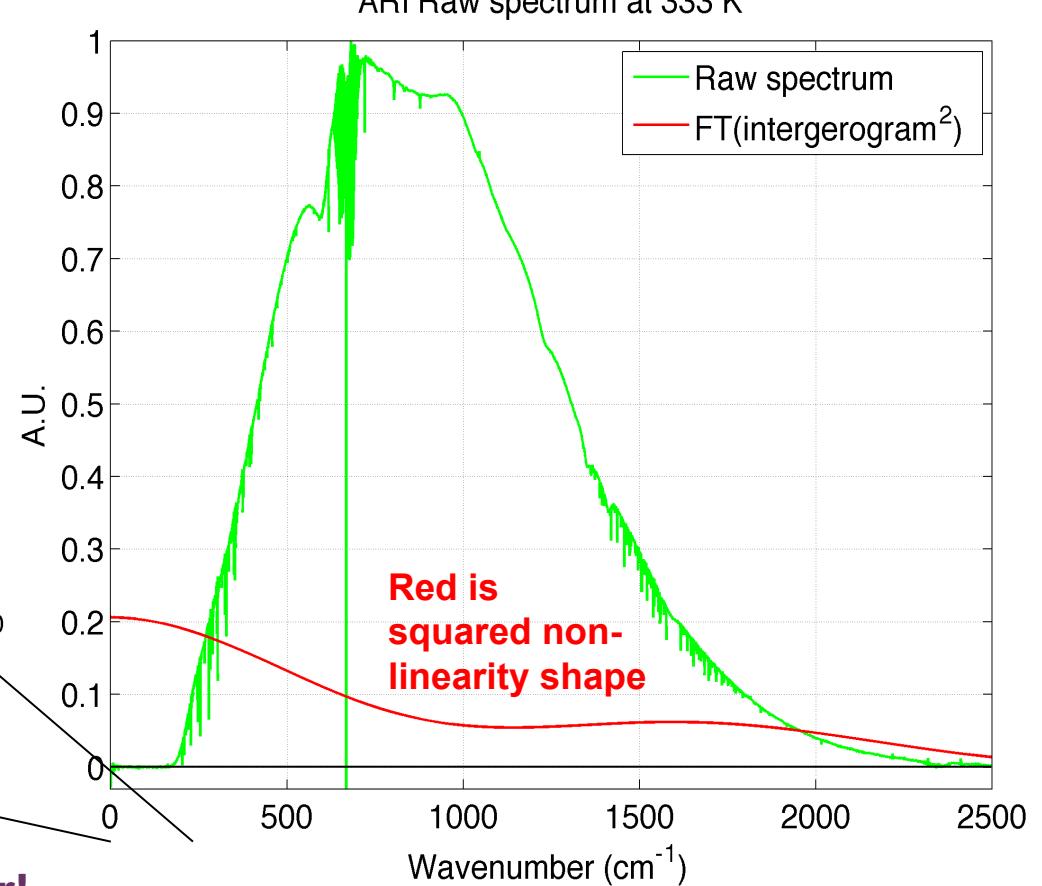
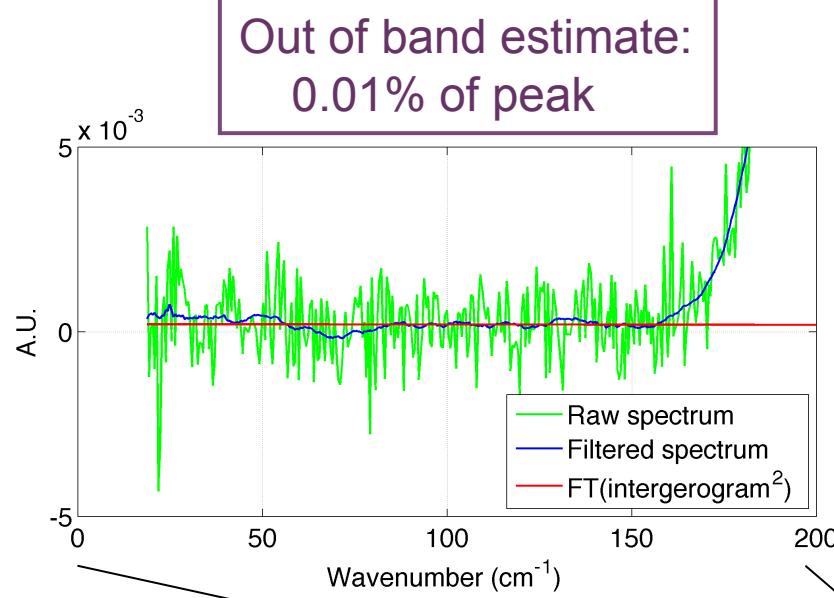
# AERI BB Emissivity (Halo, ARI-1)



# AERI BB Emissivity Comparison



# Pyroelectric Linearity

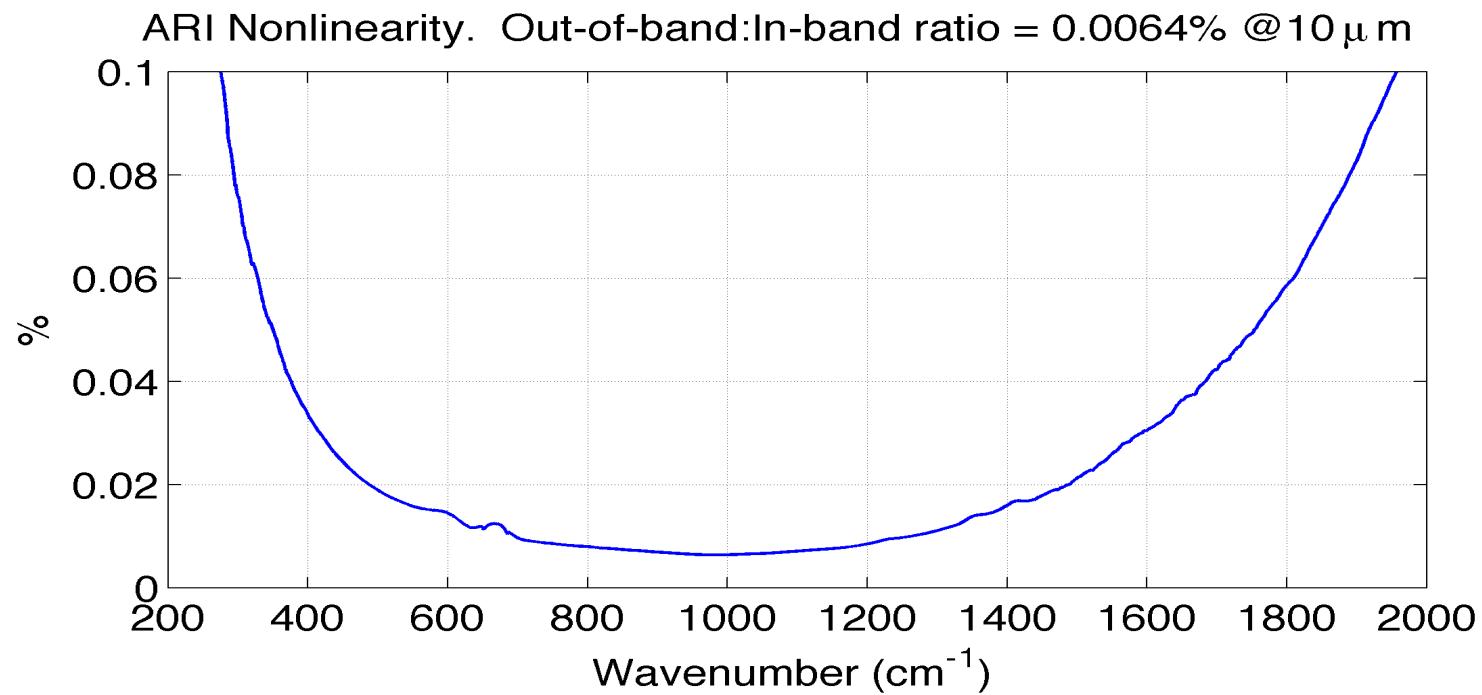


Pyro & electronics are very linear!

(Dry air purge, ~50 hour dwell)



# Pyroelectric Linearity: Estimate



Rough quantitative estimate shows high degree of linearity even for raw spectrum—effects on calibrated spectra are smaller



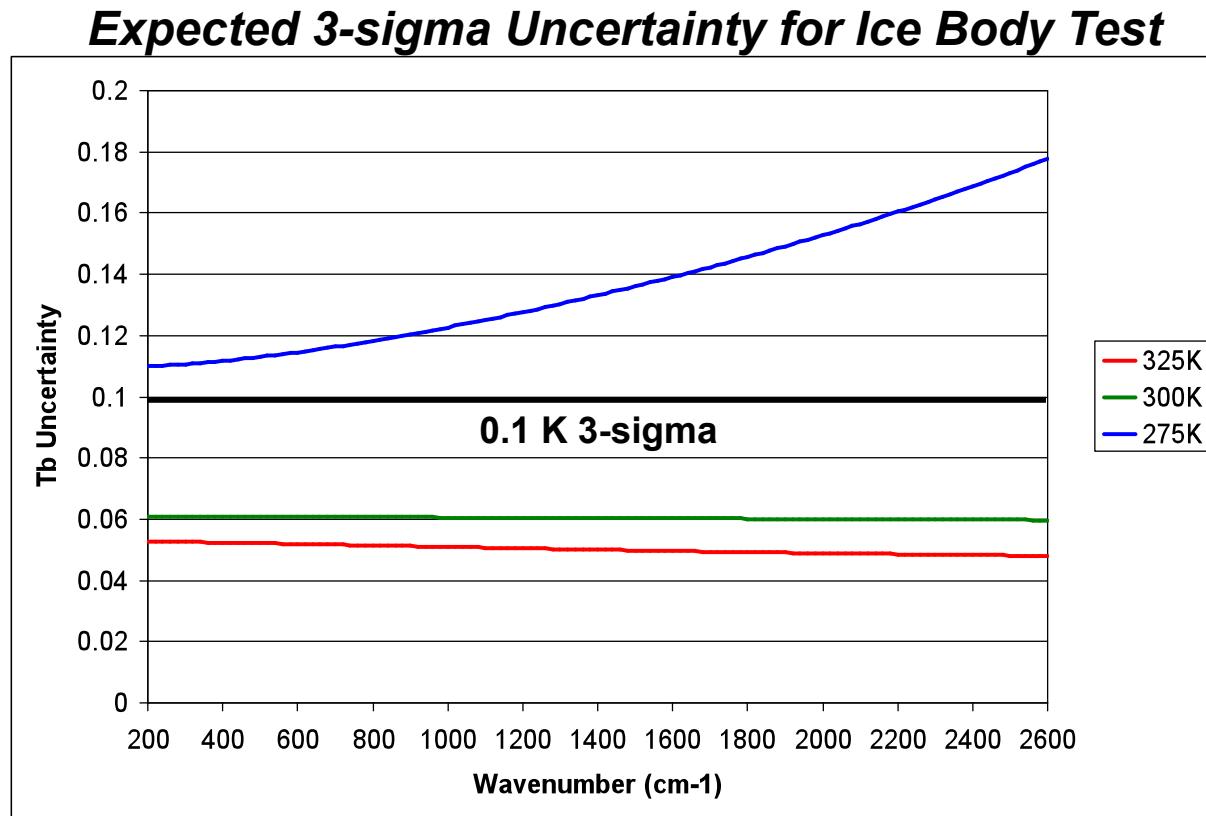
Pyroelectric detector is well suited to CLARREO

Slide 28



# Ice Body Calibration Test

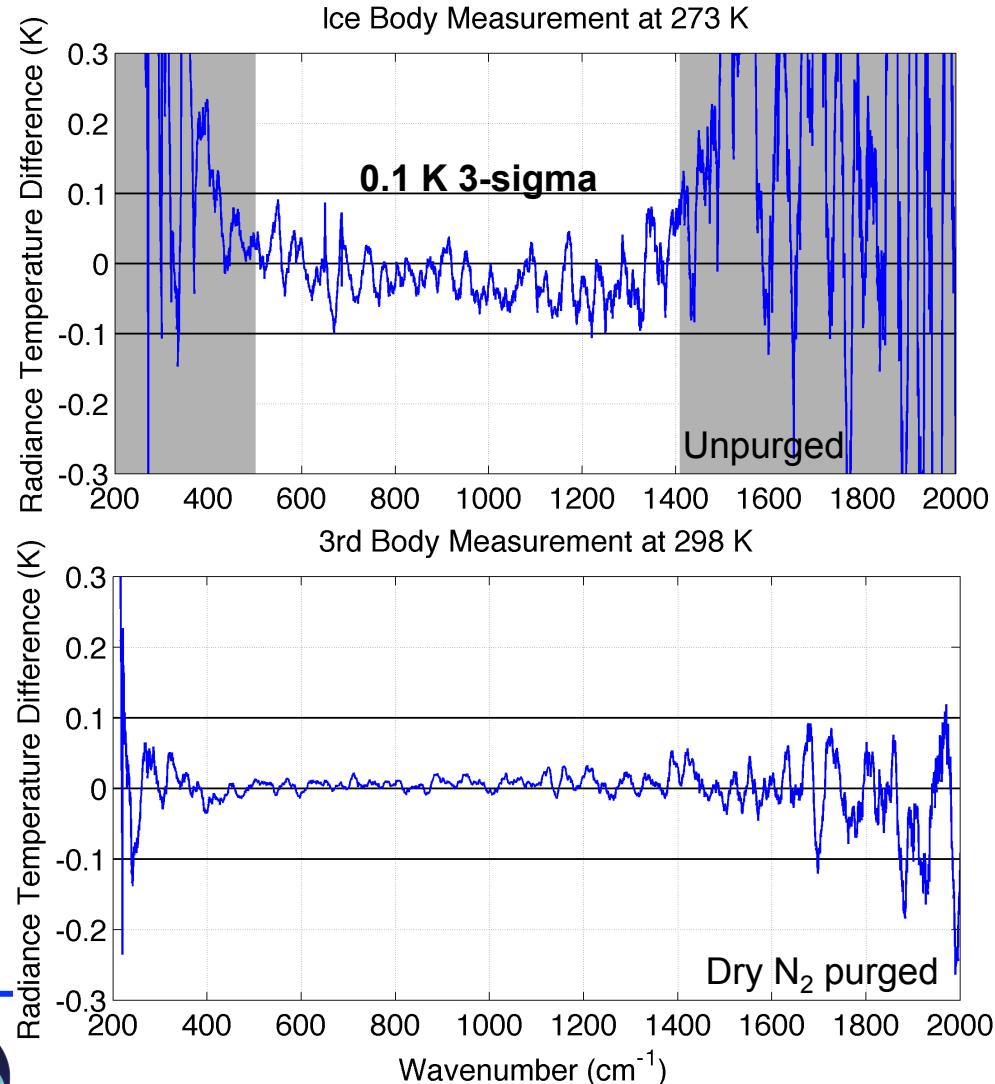
- Demanding ambient lab test
- Calibration Blackbody T's: 298 K & 317 K
- Extrapolating to 273.15 K



Same Blackbody characteristics would give  
< 0.1 K 3-sigma accuracy with a space view on-orbit



# Ice Body Calibration Test Result



- Expected Accuracy is realized
- Grayed area is affected by room water vapor
- Extrapolating enhances noise (see 298 K comparison)

12 hours test time



# Conclusions

- Proven results from high spectral resolution measurements and the recent UW/Harvard IIP developments demonstrate readiness for an IR Climate Benchmark Mission
- NASA Earth Venture-2 provides the first opportunity for getting this compelling mission into space



# Science and Society: High Accuracy Measurements for Climate and Weather

## Mission Overview

Named for the god of sky and weather, law, order, and fate, the Zeus mission will harness advances in the physics of high accuracy measurements from Earth orbit to establish a benchmark observation of global climate.

Zeus will observe spectrally resolved infrared radiances from a 90° polar orbit, creating a dataset with high information content.

